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(71) Applicant *(for all designated States except US)*: **POLYSTOR CORPORATION** [US/US]; 230 S. Vasco Road, Livermore, CA 94550 (US).

(72) Inventor; and
(75) Inventor/Applicant *(for US only)*: **COUSTIER, Fabrice** [US/US]; 6561L Cottonwood Circle, Dublin, CA 94568 (US).

(74) Agent: **AUSTIN, James, E.**; Beyer Weaver & Thomas, LLP, P.O. Box 778, Berkeley, CA 94704-0778 (US).

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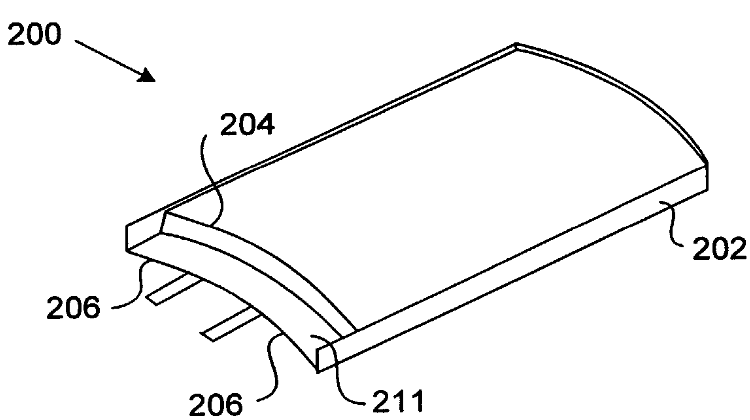
(54) **Title:** CUSTOM GEOMETRY BATTERY CELLS AND METHODS AND TOOLS FOR THEIR MANUFACTURE



(57) Abstract: An electrochemical cell having a custom shape or geometry is provided. The custom shape may include a curved portion such as a curved surface or edge. These custom geometry electrochemical cells find particular use in modern electronic devices having smaller sizes, more ergonomic designs and requiring specially shaped components. Methods for fabricating custom geometry electrochemical cells are also provided. These fabrication methods are sensitive to fabrication demands imposed by curved surfaces and alternate cell geometries. Custom tooling for fabricating battery cells having a custom shape or geometry are further provided.

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CUSTOM GEOMETRY BATTERY CELLS AND METHODS AND TOOLS FOR THEIR MANUFACTURE

BACKGROUND OF THE INVENTION

The present invention relates generally to electrochemical cells having custom geometries and their methods of fabrication. More particularly, the present invention relates to the composition and fabrication of electrochemical battery cells, such as lithium-ion secondary cells, having curved surfaces and variable geometries.

Cell containers come in two standard geometries of various sizes depending upon energy and power requirements as well as the compartment in which the cell will be housed. Cylindrical and prismatic cells are now primarily used, although cylindrical cells are more common. Cylindrical cell containers typically have two components: a cylindrical can and a positive terminal cap. Prismatic batteries come in many sizes, but all are rectangular in shape and have three principal dimensions: a length, width and thickness. Note that cylindrical cells have only two principal dimensions: a length and a diameter. Due to their different shape and construction, prismatic cells and cylindrical cells typically have different compositions and fabrication methods.

Modern electronic devices are calling for smaller sizes and more ergonomic designs. The smaller sizes and more ergonomic designs often require specially shaped components. While conventional cylindrical and prismatic cells provide suitable energy and power requirements for many applications, they do not appear to have been designed to address the divergent structural requirements of many modern electronic devices. Conventional cylindrical and prismatic battery cells require an abundant amount of space and are often too bulky for many modern electronic device designs. In view of the foregoing, there are desired improved battery cell shapes and methods for their fabrication.

SUMMARY OF THE INVENTION

The present invention provides an electrochemical cell having a custom shape or geometry. The custom shape may include a curved portion such as a curved surface or edge. These custom shaped electrochemical cells find particular use in modern electronic devices having smaller sizes, more ergonomic designs and requiring specially shaped components.

In one aspect, the present invention provides methods for fabricating electrochemical cells having a custom geometry. These fabrication methods are sensitive to fabrication demands imposed by curved surfaces and alternate cell geometries. The present invention also provides custom tooling for fabricating electrochemical cells having a custom shape or geometry.

In one aspect of the invention, a custom shape or geometry of an electrochemical cell is formed during lamination. In many cases, the cell or cell components are compliant before lamination. After lamination, the cell or cell components have been hardened to a rigidity suitable for cell use. In one embodiment, custom tools are used during lamination to produce the custom geometry of the cell or its components. The custom tools may include custom dies having specially designed plates which match the desired geometry of the custom geometry cell or cell components.

In another aspect of the invention, special techniques and custom tooling are used during sealing of an electrochemical cell which accommodate for curvature or special geometry in the cell. The custom tooling may include a sealing bar having curvature corresponding to a curved surface or curved edge of a custom geometry electrochemical cell.

In one aspect, the invention relates to an electrochemical cell. The electrochemical cell includes a cell container having at least one curved surface. The electrochemical cell also includes a negative electrode provided within the cell container. The electrochemical cell further includes a separator provided within the cell container. The electrochemical cell additionally includes a positive electrode provided within the cell container. A portion of the positive electrode has a curved

surface with substantially the same radius of curvature as the at least one curved surface of the cell container.

In another aspect, the invention relates to a custom geometry electrochemical cell comprising a cell container having at least one curved surface. The custom geometry electrochemical cell includes a negative electrode, a separator, and a positive electrode – each provided within the cell container. A portion of the positive electrode has a curved surface. The custom geometry electrochemical cell has a ratio between its minimum and maximum dimensions between about 3:1 and 300:1.

In yet another aspect, the present invention relates to a method of fabricating a custom geometry electrochemical cell. The method includes receiving a positive electrode, a separator and a negative electrode as one or more layers. The method further includes inserting the one more layers into a cell container. The method also includes sealing the cell container. The method additionally includes laminating the one or more layers wherein the one or more layers comprise a curved geometry after lamination.

In still another aspect, the present invention relates to a method of laminating an electrochemical cell structure comprising one or more layers, each of the layers comprising a negative electrode, a separator and a positive electrode. The method comprising laminating the one or more layers, wherein the one or more layers comprise a curved geometry after the lamination.

In another aspect, the present invention relates to a custom die for laminating a custom geometry electrochemical cell. The custom die includes a first plate and having a first cell reception surface corresponding to a desired geometry for a first portion of the custom geometry electrochemical cell. The custom die also includes a second plate and having a second cell reception surface corresponding to a desired geometry for a second portion of the custom geometry electrochemical cell, wherein one of the first cell reception surface and the second cell reception surface include curvature.

In yet another aspect, the present invention relates to a method of sealing a portion of an electrochemical cell, the method comprising sealing the portion of the

cell using one or more sealing bars, wherein the portion comprises a curved geometry after sealing.

In still another aspect, the present invention relates to a custom sealing apparatus for sealing a custom geometry electrochemical cell. The custom sealing apparatus includes a first sealing bar having a first sealing surface corresponding to a desired geometry for a first portion of the custom geometry electrochemical cell. The custom sealing apparatus also includes a second sealing bar having a second sealing surface corresponding to a desired geometry for a second portion of the custom geometry electrochemical cell, wherein at least one of the first sealing surface and the second sealing surface include curvature.

These and other features and advantages of the present invention will be described in the following description of the invention and associated figures.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A illustrates a top perspective view of a custom geometry electrochemical cell having curved geometry in accordance with one embodiment of the present invention.

FIG. 1B illustrates a top elevation view of a custom geometry electrochemical cell having curved geometry in accordance with one embodiment of the present invention.

FIG. 1C illustrates a cross-section of the cell of FIG. 1B along a line A-A in accordance with one embodiment of the present invention.

FIG. 1D illustrates a side elevation view of a custom geometry electrochemical cell having curved geometry in accordance with one embodiment of the present invention.

FIG. 2A illustrates an enlarged cross-section of the cell of FIG. 1B along the line A-A in accordance with one embodiment of the present invention.

FIG. 2B illustrates a portion of a single laminate layer of the jellyroll design of FIG. 2A in accordance with one embodiment of the present invention.

FIG. 3 illustrates a process flow for manufacturing an electrochemical cell having a custom geometry in accordance with one embodiment of the present invention.

FIG. 4A illustrates a process flow for laminating an electrochemical cell having a custom geometry including a curved surface in accordance with one embodiment of the present invention.

FIG. 4B illustrates a custom die for laminating an electrochemical cell having a curved geometry in accordance with one embodiment of the present invention.

FIG. 5A illustrates a process flow for sealing an electrochemical cell having a custom geometry including one or more curved edges in accordance with one embodiment of the present invention.

FIG. 5B illustrates custom top and bottom bars for use in sealing an electrochemical cell having a custom geometry in accordance with one embodiment of the present invention.

FIG. 6A illustrates a curved polymer stack electrochemical cell in accordance with one embodiment of the present invention.

FIG. 6B illustrates a portion of a laminate layer found in the polymer stack of FIG. 6A.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention will now be described in detail with reference to a few preferred embodiments thereof as illustrated in the accompanying drawings. In the following description, numerous specific details are set forth in order to provide a thorough understanding of the present invention. It will be apparent, however, to one skilled in the art, that the present invention may be practiced without some or all of these specific details. In other instances, well known process steps and/or structures have not been described in detail in order to not unnecessarily obscure the present invention.

FIGs. 1A, 1B, 1C and 1D illustrate a top perspective view, a top elevation view, a cross-section along a line A-A 219, and a side elevation view, respectively, of a custom geometry electrochemical cell 200 having curved geometry in accordance with one embodiment of the present invention. The cell 200 includes a cell container 202 having a curved surface. The cell container 202 provides mechanical protection for the internal components of the cell 200 and a seal from the external environment. The cell container 202 includes top and bottom curved surfaces 204 and 206 respectively. The top and bottom curved surfaces 204 and 206 have about the same radius of curvature and are substantially parallel. In one embodiment, the cell container 202 is a soft metal laminate package comprising aluminum which is stamped into shape.

FIG. 2A illustrates an enlarged cross-section of the cell 200 along the line A-A 219 of FIG. 1B in accordance with one embodiment of the present invention. The electrochemical cell 200 is a lithium-ion secondary battery cell that uses a curved "jellyroll" design 210. The curved jellyroll design 210 is formed by winding a laminate layer 212.

FIG. 2B illustrates a curved portion 214 of a single laminate layer 212 of the jellyroll design 210 in accordance with one embodiment of the present invention. The curved portion 214 includes a separator 216 interposed between a positive electrode 218 and a negative electrode 220. The positive electrode 218 and negative electrode 220 have a curved portion 217 with substantially the same radius of curvature as curved surfaces 204 and 206. The separator 216 is generally porous. The electrodes 216 and 218 are typically formed on current collectors, which may be composed of a highly conductive metal, such as copper or aluminum. The positive electrode 218 comprises a cathode material 224 on an aluminum foil 226. The negative electrode 220 comprises an anode material 228 on a copper foil 230. The aluminum foil 226 and the copper foil 230 collect current for the positive electrode 218 and the negative electrode 220 respectively.

The separator 216 is an ion conducting material for conducting ions between the positive electrode 218 and the negative electrode 220. In one embodiment, the separator 216 is a porous polymer film which may be filled with an electrolyte. By way of example, the electrolyte is an organic solvent including a lithium salt. In another embodiment, the separator 216 is a gel polymer layer or solid polymer layer that insulates the positive electrode 218 and the negative electrode 220 while conducting ions therebetween. To help adhere the separator 216 to the cathode material 224 and the anode material 228, a layer of binder material 232 may be coated onto the top and bottom surface of the separator 216. In one embodiment, the binder material 232 is the same binder material as used in the cathode material 224 and the anode material 228. During lamination, the binder material 232 improves bonding between the separator 216 and the cathode material 224 as well as contact between the separator 216 any anode material 228.

Returning to FIGs. 1A-D and 2A, a positive lead 234 is welded to an uncoated portion of the aluminum foil 226 and extends from inside the cell container 202 to the exterior of the cell container 202. A negative lead 236 is welded an uncoated portion of to the copper foil 230 and similarly extends from inside the cell container 202 to the exterior of the cell container 202. The leads 234 and 236 provide external electrical connections for the cell 200.

In one embodiment, the cell container 202 comprises two aluminum sheets formed to dimensions for holding the jellyroll 210. More specifically, the cell container 202 comprises a bottom cup 203 of aluminum suitably stamped and curved to receive the jellyroll 210. A top aluminum sheet 205, which is also curved, is used to cover the curved jellyroll 210 and the cup 203. The cell container 202 may also include other components used in conventional electrochemical cell packaging as are well known in the art. These components may include an inner polypropylene lining, and a nylon or polyester outer shell.

The cell 200 may be described by a width 238, a thickness 240 and a length 241 (FIGs. 1B, 1C and 2A). Using these dimensions, custom geometry battery cells in accordance with the present invention may be described by a minimum dimension and a maximum dimension. For example, for the cell 200, the minimum dimension is the thickness 240 and the maximum dimension is the length 241. Further, custom geometry battery cells in accordance with the present invention may be described by a ratio of the maximum dimension and the minimum dimension. In accordance with one embodiment of the present invention, at least one of the width 238, the thickness 240 and the length 241 describes a portion of a cell having curvature.

By way of example, cell thicknesses 240 suitable for the present invention may range from about 1 millimeter to 20 millimeters. Widths 238 suitable for the present invention may range from about 10 millimeters to 300 millimeters. Lengths 241 suitable for the present invention may range from 10 millimeters to 300 millimeters. In a specific embodiment, a cell of the present invention may have a thickness 240 of 3 to 4 millimeters and a width 238 of 30 to 50 millimeters. In another specific embodiment, a cell of the present invention may have a thickness 240

of 7 millimeters and a width 238 of 50 millimeters. In one embodiment, the ratio of the maximum dimension and the minimum dimension may range from 3:1 to 300:1.

Custom geometry battery cells in accordance with the present invention having a substantially consistent thickness 240 across the width 238, such as the cell 200, may be characterized using an aspect ratio. The aspect ratio of an electrochemical cell, as used herein, refers to a ratio of two dimensions of the cell, one of which is the cell's thickness 240. In particular, the aspect ratio as used herein refers to the ratio of the maximum dimension of the cell to its minimum dimension. In one embodiment, the aspect ratio may range from 3:1 to 300:1. Any custom geometry battery cell having substantially parallel curved edges may be characterized using an aspect ratio. Further, any electrochemical cell having a constant number of laminate layers, e.g. in a jellyroll design or a stack, across the width 238 may be characterized using an aspect ratio.

In one embodiment, the electrochemical cell 200 is a gel polymer battery including a gel forming polymer. More specifically, the electrolyte used in the cell 200 is in a gel state at the end of manufacturing. Suitable materials for the separator 216 in a gel polymer battery are known to those of skill in the art and include polyalkenes, polyethylene, polypropylene, polytetrafluoroethylene, polystyrene, polyethyleneterephtalate, ethylene propylene diene monomer, nylon and any combinations thereof. In one embodiment, the cathode material 224 and the anode material 228 are bonded together and to the current collector using a homopolymer. Other suitable materials for the gel forming polymer include polyvinylidene fluoride (PVDF), PVDF-HFP co-polymers, PVDF-PFTE copolymers and combinations, polyurethane, polyethylene oxide, polyacrylonitrile, polymethylacrylate, polyacrylamide, polyvinylacetate, polyvinylpyrrolidone, polytetraethylene glycol diacrylate, and copolymers or combinations of any of the above.

The electrodes 216 and 218 may be composed of appropriate materials known to those of skill in the art. Suitable materials for the positive electrode 218 include, for example, carbon (as an electronic conductor), active material (e.g., lithium cobalt oxide, lithium manganese oxide, or lithium nickel oxide), and a binder (such as

PVDF). Suitable materials for the negative electrode 220 include, for example, carbon as an active material with a binder (such as PVDF).

In one embodiment, the present invention provides alternative methods for fabricating electrochemical cells having a custom geometry such as a curved surface. As will be described below, these alternative fabrication techniques are sensitive to fabrication demands imposed by cells having alternate geometries such as curved surfaces. FIG. 3 illustrates a process flow 300 for fabricating an electrochemical cell having a custom geometry in accordance with one embodiment of the present invention. Processes in accordance with the present invention may include up to several additional steps not described or illustrated here in order not to obscure the present invention.

The process flow 300 describes the fabrication of an electrochemical cell including a jellyroll design having a custom geometry in accordance with one embodiment of the present invention. The process flow 300 begins by receiving and assembling, if necessary, the active chemical components of the electrochemical cell (302). In one embodiment, constructing the jellyroll begins by coating a cathode material containing PVDF binder (positive electrode) onto an aluminum foil using a casting process. Similarly, an anode material containing PVDF binder (negative electrode) is coated onto a copper foil. Positive and negative leads are then welded onto uncoated portions of the aluminum foil and the copper foil respectively. A PVDF coated separator is then added between the cathode and the anode. The aluminum foil and the copper foil, with the separator, anode, and cathode between them, are then wound to form the jellyroll (304). The jellyroll design is wound using winding techniques as are well known in the art.

The jellyroll is then inserted within a cell container (306). The cell container may be a preformed package comprising one or more aluminum sheets or an aluminum laminate formed to dimensions for holding the jellyroll. More specifically, the preformed package may include a bottom cup formed from a stamped sheet of aluminum. A top aluminum sheet, which may also be stamped to a suitable curvature, is then used to cover the jellyroll and the cup. At this point, any sides of the package not used during injection of the electrolyte may be sealed (308). In some

embodiments, this may include the use of specialized tooling which accommodates for curved surfaces of the cell container. It should be noted that some sides of the cell container may be sealed with conventional tooling while others may be sealed using the custom tooling which accommodates for curved surfaces.

Electrolyte is then injected into the package (310). The remainder of the package is then sealed (312). In one embodiment, the package is vacuum sealed using specialized tooling which accommodates for curved surfaces in the cell. The package is then laminated (314). According to one aspect of the present invention, formation of curved geometry is performed during lamination.

For the process flow 300, lamination (312) is a two-stage process. In the first stage, the package is placed between two custom lamination plates and heated. The custom lamination plates may be shaped according to a desired geometry of the cell. In a specific embodiment, the cell is placed between the two custom plates and laminated at 90 degrees Celsius for ten minutes. Pressure may also be applied by the custom plates to the cell and its components to maintain good connection between the layers during lamination. In the second stage, the package is placed between two custom plates and cooled. In one embodiment, the custom plates used during the cooling stage are substantially identical to the custom plates used during heating. In a specific embodiment, the cell is placed between the two custom plates and held at room temperature for a duration of two minutes. Again, pressure may be added. After lamination, the cell produced by the process flow 300 is sufficiently stiff and will retain its custom geometry during use.

For some electrochemical cells of the present invention, the cell container and the components it contains, e.g. the jellyroll, are flexible before lamination. In gel polymer batteries for example, the binder material used to adhere the separator to the anode and cathode is a soft polymer. After lamination, components within the cell container may harden to provide a stiff plastic. Correspondingly, the electrochemical cell will take a shape according to the shape of the plates used during lamination. In other embodiments, components within the cell container are laminated before insertion into the cell container. In this case, the cell container may be rigid and preformed to the geometry of the laminated components.

Lamination using flat plates designed for prismatic cells may be unsuitable for custom geometry battery cells. More specifically, lamination plates which do not match a desired custom geometry may not produce the desired geometry or may induce stresses on the cell during lamination. These stresses on the battery cell and its components may result in swells, gassing, and other undesirable effects which may affect adherence between layers of the jellyroll or otherwise diminish cell performance. As lamination using conventional equipment may be unsuitable for a custom geometry battery cell and its components, the present invention provides fabrication methods and apparatus for lamination of custom geometry battery cells that produce the desired cell geometry and minimize stresses during lamination.

In one embodiment, custom geometry and curvature of an electrochemical cell is solely formed during lamination. This may be preferable for cell batteries having minimal curvature. For example, the container of an electrochemical cell having minimal curvature may begin lamination having a prismatic shape. Curvature and shaping is then added during lamination provided that the curvature is not sufficient to rupture the packaging. This may include containers which are completely sealed prior to and during lamination. In another embodiment, an electrochemical cell is already substantially pre-curved before lamination and the lamination process acts to finalize and/or solidify any curvature in the cell. By way of example, the cell container may be pre-shaped according to the desired geometry of the cell. Then, the cell container may be sealed according to any curvature or custom geometry as will be described in more detail below with respect to FIG. 5A. Finally, the lamination process acts to finalize any curvature in the cell. Lamination according to the present invention may include a number of successive laminations each performed under different conditions, e.g. an energy input lamination followed by a cooling lamination, or may a single lamination, e.g. either an energy input lamination or a cooling lamination.

FIG. 4A illustrates a process flow 400 for laminating an electrochemical cell having a custom geometry including a curved surface in accordance with one embodiment of the present invention. Processes in accordance with the present

invention may include up to several additional steps not described or illustrated here in order not to obscure the present invention.

The process flow 400 begins placing the cell at least partially within a custom die (402) . The custom die includes a set of plates having curvature corresponding to the desired geometry of a portion of the battery cell. For some battery cells, e.g., for gel polymer cells, the cell container and its components are soft and malleable thus conform to the geometry of the plates. Energy is then supplied to the plates to facilitate the lamination of layers within the cell (404). In one embodiment, the plates are heated at an elevated temperature. By way of example, for gel polymer battery cells, heat may be supplied at a constant temperature anywhere from about 30 degrees Celsius to 150 degrees Celsius for duration of about 1/2 minutes to 20 minutes. In a specific embodiment, heat is supplied at a constant temperature of 90 degrees Celsius for 10 minutes for a gel polymer battery cell. In another embodiment, ultrasonic welding is used to provide energy for lamination. In addition to the energy supplied, pressure may be applied to the cell by the custom plates. By way of example, pressures in the range of about 10 pounds per square inch to 300 pounds per square inch are suitable for use with the present invention. In a specific embodiment, pressure is supplied at about 36 pounds per square inch.

The cell is then moved to a second custom die for lamination while cooling (406). The second custom die includes a set of custom plates with geometry corresponding to the desired geometry of the battery cell. The custom plates used while cooling conform the shape of the cell as received from the first lamination to the desired shape of the cell, if they are different. In one embodiment, the custom plates used at the cooling station (404) have the same geometry as the custom plates used during energy input (406). During lamination while cooling (408), pressure may be applied to the cell. The pressure may act to maintain any geometry obtained during the heating lamination which may be altered while the cell cools.

In one embodiment, lamination while cooling is performed at room temperature for duration in the range of about 1/2 minutes to 20 minutes. Pressures suitable for lamination in this case may range from about 10 to 300 pounds per square inch. In a specific embodiment, cooling occurs for about two minutes with the

pressure of about 100 pounds per square inch. As the cell cools, material within the cell hardens to the shape provided by the custom plates and may retain this shape over the lifetime of the cell.

FIG. 4B illustrates a custom die 450 for laminating a custom geometry electrochemical cell in accordance with one embodiment of the present invention. The die includes a top plate 452 and a bottom plate 454. The top and bottom plates 452 and 454 each include a cell reception surface 456 and 458, respectively. The cell reception surfaces 456 and 458 each have a geometry corresponding to the desired geometry of a portion of the custom geometry cell. At least a portion of the cell then fits between the top and bottom plates 452 and 454 and conforms to the shape provided by the surfaces 456 and 458.

A die in accordance with the present invention is typically custom-made for lamination of a particular cell. By way of example, the top and bottom plates 452 and 454 are custom-made for the battery cell 200. As battery cell geometries in accordance with the present invention may vary greatly, the plates used for lamination of a custom geometry battery cell may take any shape, size or number and may comply with any conventional laminating and fixturing rules as are well-known in the art. It should be noted that the design goals of the custom plates may vary. In one embodiment, the top and bottom plates 452 and 454 are designed to provide the final shape of the cell after manufacturing. In another embodiment, the top and bottom plates 452 and 454 are designed to provide the final shape of a jellyroll or stack before insertion into a package. The custom die 450 may also be used for other processes involving a custom geometry battery cell. By way of example, the custom die 450, or a similar custom die, may also be used for curing and gelling of the cell or cell components.

The die 450 is suitable for use with any conventional laminating machine. By way of example, the die 450 is suitable for use with a Model C, Carver Press laminating machine as produced by Carver Inc. of Wabash, IN. The top and bottom plates 452 and 454 may be constructed according to conventional tooling and fixturing techniques as are well-known in the art. By way of example, steel is a suitable material for the plates 452 and 454.

Having briefly discussed an exemplary method and apparatus suitable for lamination of a custom geometry cell in accordance with the present invention, other fabrication methods and apparatus for fabricating a custom geometry electrochemical cell will now be discussed. As mentioned previously, the present invention also includes the use of alternative methods and apparatus for sealing a custom geometry electrochemical cell.

Conventional sealing using flat tooling designed for prismatic battery cells may be unsuitable for a custom geometry battery cell. For example, after sealing a cell having prismatic dimensions with conventional flat sealing equipment, stresses may be induced during lamination when the cell is laminated from its flat dimensions to a curved geometry. These stresses may form cracks in a seal which may lead to leakage. Alternately, leads within the battery cell may stretch as a result of sealing tooling which does not match the custom cell geometry. Thus, in one aspect of the present invention, custom sealing methods and apparatus are used when sealing a custom geometry electrochemical cell.

FIG. 5A illustrates a process flow 500 for sealing a custom geometry electrochemical cell including one or more curved portions in accordance with one embodiment of the present invention. The curved portions may include one or more curved edges and/or one or more curved surfaces of the custom geometry cell. By way of example, the cell 200 (FIGs. 1A-D) includes a curved edge 206 and a curved seam 211 which are to be sealed. In one embodiment, the process flow 500 is suitable for use when sealing edges of a cell that are not used during injection of an electrolyte. In another embodiment, the process flow 500 is suitable when sealing edges of a cell after injection of electrolyte. Processes in accordance with the present invention may include up to several additional steps not described or illustrated here in order not to obscure the present invention.

The process flow 500 begins by selecting the next portion of the cell to be sealed and determining whether it is straight or not (502). If the next portion is not straight, e.g., curved or alternatively shaped, a bar sealer having custom bars may be used. The custom bars include geometry determined by the portion to be sealed. Sealing begins by locating the custom bars on the portion (504). Heat is then applied

for a suitable duration to form a seal (506). By way of example, the custom sealing bars may be heated to temperature from about 50 degrees Celsius to 300 degrees Celsius for a duration of several milliseconds to about 30 seconds. In a specific embodiment, the custom bars may be heated to 200 degrees Celsius for about two seconds. The process flow 500 and determines if there is another edge to be sealed (508).

For straight edges of the battery cell, conventional sealing bars may be used. Sealing of a flat edge begins by locating the bars (510). Heat is then applied for a suitable duration to form a seal (512). Sealing temperatures and durations for flat surfaces are well-known in the art. The process flow 500 then determines if there is another edge to be sealed (508). Sealing may be preceded by the injection of an electrolyte into the electrochemical cell. If so, a vacuum may be applied to remove any air from the cell before injection of the electrolyte. The portion of the cell used for electrolyte injection is then sealed according to the process flow 500.

In one aspect of the present invention, surfaces and/or edges having a custom geometry are sealed using custom tooling. FIG. 5B illustrates custom top and bottom bars 552 and 554 for use in sealing a portion of a custom geometry electrochemical cell in accordance with one embodiment of the present invention. The custom bars 552 and 554 each include a sealing surface 556 and 558, respectively. The surfaces 556 and 558 each have a geometry corresponding to a desired geometry for a portion of the cell. As mentioned previously, the desired geometry of the portion may include curvature. By way of example, the surfaces 556 and 558 each have a geometry corresponding to the curved seam 211 included in the cell 200 (FIG. 1A). The cell 200 at least partially fits between the custom top and bottom bars 552 and 554. More specifically, the seam 211 at least partially fits between the surfaces 556 and 558.

Custom bars in accordance with the present invention are typically custom-made for a particular portion or edge of an electrochemical cell. In one embodiment, the bars are designed relative to the cell's final shape after fabrication. In another embodiment, the custom bars are designed to minimize stresses during subsequent fabrication procedures. By way of example, the custom bars may be designed to minimize stresses on the sealing area during subsequent lamination.

The custom bars 552 and 554 are suitable for use with any conventional bar sealer. By way of example, custom bars 552 and 554 are suitable for use with a bar sealing machine as produced by Sencorp Systems Inc. of Hyannis, MA. The custom bars 552 and 554 may be constructed according to conventional techniques as are well-known in the art. By way of example, steel or aluminum are suitable materials for use in the bars 552 and 554.

Having briefly discussed several specific examples of a custom geometry electrochemical cell in accordance with the present invention, and a few alternative fabrication techniques for manufacturing the cell in accordance with the present invention, several other aspects of custom geometry electrochemical cells and their fabrication will now be expanded upon.

Fabrication processes used in the present invention may vary in order while still producing a desired custom geometry cell. In one embodiment, an electrochemical cell is fabricated by laminating a wet jellyroll before insertion into a cell container. In this case, a cathode (positive electrode) material containing binder, such as PVDF, is coated onto an aluminum foil using a casting process. Similarly, an anode (negative electrode) material containing PVDF binder is coated onto a copper foil. The positive and negative leads are then welded onto uncoated portions of the aluminum foil and the copper foil respectively. A PVDF coated separator is then added between the cathode and the anode. The aluminum foil and the copper foil, with the separator, anode, and cathode between them, are then wound to form the jellyroll.

At this point, the jellyroll is laminated under pressure and heat to form a laminate having a curved geometry. Lamination includes placing the jellyroll in a die between two custom plates which are shaped according to the desired curvature of the jellyroll. In a specific embodiment, the jellyroll is laminated at about 90 degrees Celsius for about ten minutes at a pressure of about 36 pounds per square inch. The pressure and heat may also evaporate the solvent used to apply the binder. The jellyroll may then be placed between two custom lamination plates at room temperature for a duration of about 10 minutes. At this point, the jellyroll is sufficiently stiff and may retains its shape during use.

The hard jellyroll is then placed in a cell container which may be pre-formed to a geometry matching or similar to that of the jellyroll. At this point, the cell container may be sealed. In some embodiments, this may include the use of specialized tooling which accommodates for curved edges in the container, for example, as described above. Electrolyte may also be injected into the package before the package is sealed.

The present invention is also suitable for any electrochemical cell composition. In one aspect, the present invention is suitable for use with lithium-ion batteries. This may include, for example, gel-polymer batteries as well as solid-state polymer batteries. The present invention is also suitable for cells other than lithium containing batteries having a custom geometry.

The fabrication techniques and custom fabrication apparatus of the present invention may be used for any custom geometry cell and are not limited to polymer cell batteries which use a liquid electrolyte or a solvent. In one embodiment, the present invention is suitable to provide curvature for cells having a cathode, a separator and an anode in which the separator is a solid plastic sheet. In addition, the fabrication techniques and custom fabrication apparatus of the present invention are suitable for any gel-polymer battery or polymer battery produced by conventional methods.

FIG. 6A illustrates a curved polymer stack electrochemical cell 600 in accordance with one embodiment of the present invention. The polymer stack cell 600 includes a cell container 601 which encapsulates a polymer stack 606. The cell container 601 has curved surfaces on its top and bottom faces 602 and 604 respectively. The top and bottom faces 602 and 604 have substantially the same radius of curvature and are substantially in parallel. The polymer stack 606 comprises a set of layers 605, each having a curvature with about the same radius of curvature as the top and bottom faces 602 and 604. The polymer stack 606 includes a curved solid polymer layer as the separator for the curved polymer stack battery cell 600.

FIG. 6B illustrates a portion 610 of a laminate layer 605 found in the polymer stack 606 of FIG. 6A. The laminate layer 605 includes an aluminum grid 612 which acts as a current collector for the cell 600. A curved cathode layer 614 acts as the

positive electrode for the cell 600 and is squeezed into the aluminum grid 612 to establish contact between the aluminum grid 612 and the cathode layer 614. A curved solid polymer layer 615 is situated between the curved cathode layer 614 and a curved anode layer 616 and acts to prevent shorting between the cathode layer 614 and the anode layer 616 and also acts as an electrolyte to conduct ions between the two. The curved anode layer 616 acts as the negative electrode for the cell 600. A second curved copper grid 618 acts as a second current collector for the cell 600. The curved anode layer 616 is squeezed onto the second curved copper grid 618 to establish contact between the anode layer 616 and the copper grid 618. In one embodiment, the cell 600 includes a negative lithium metal electrode in the curved anode layer 616 and the curved cathode layer 614.

The custom cell geometry and fabrication techniques of the present invention are suitable for any polymer battery made using a polymer membrane. Suitable materials for the curved polymer layer 615 used in the curved polymer stack battery cell 600 include polyvinylidene fluoride (PVDF), PVDF-HFP copolymers, PVDF-PTFE copolymers and combinations, polyurethane, polyethylene oxide, polyacrylonitrile, polymethylacrylate, polyacrylamide, polyvinylacetate, polyvinylpyrrolidone, polytetraethylene glycol diacrylate, polyethylene, polypropylene, and any copolymers or combinations of any of the above. The electrolyte used in these batteries at the end of fabrication may be a solid, liquid or gel.

Fabrication of the cell 600 and the polymer stack 606 may include a combination of conventional fabrication methods with one or more of the fabrication apparatus and/or techniques of the present invention.

Although the present invention has been discussed primarily with respect to a simple curved the cell as in FIGs. 1A-D, the present invention is suitable for any cell geometry. Generally speaking, the present invention is suitable for any form of electrochemical cell, which at the end of manufacturing, has a custom geometry. The custom geometry may include, for example, any non-prismatic shape, a cell including at least one curved feature or surface, a cell having specific ergonomic geometry for a particular electronics application, a custom cell having nonparallel straight edges,

oddly shaped sides, etc. For custom geometry cells having a curved surface and/or edge, the curvature may include any suitable radius of curvature. By way of example, the radius of curvature may be from about ¼ inch to ten feet. For custom geometry cells used in electronics applications, such as cell phones, the radius of curvature may be determined by an ergonomic shape of the electronic device housing. In a specific embodiment to provide a battery for an electronic device that conforms to a person's forearm, the radius of curvature of a cell is designed corresponding to the radius of the person's forearm. In some cases, the radius of curvature may be large enough such that the cell appears only slightly curved. In one embodiment, the cell may have a custom geometry suitable for placement behind a portion or all of a visual display on a portable computer. It should also be noted that a surface or edge in accordance with the present invention may have multiple curved features each having its own radius of curvature.

In one aspect, the present invention covers any custom geometry cell that substantially retains its shape after manufacturing. Thus, the present invention is suitable for use with any cell which is laminated, cured or gelled. This may include any form of lithium ion or lithium battery using any type of packaging such as a soft metal laminate or a hard shell. Custom geometry electrochemical cells in accordance with the present invention are also not confined to any process, fabrication techniques or fabrication apparatus described herein. This may include complex custom dies having numerous parts for holding and conforming the shape of a particular cell. Alternatively, this includes any sealing bar configuration for sealing an oddly shaped edge of a cell.

Advantageously, the present invention provides battery cells having custom shapes and geometries. These custom shaped battery cells find wide use in modern electronic devices having smaller sizes, more ergonomic designs and requiring specially shaped components. The present invention is suitable for use with any portable electronic device. By way of example, the present invention is suitable for use with cellular telephones, pagers, portable computers, MP3 players, etc.

While this invention has been described in terms of several preferred embodiments, there are alterations, permutations, and equivalents which fall within

the scope of this invention which have been omitted for brevity's sake. By way of example, although the present invention has been discussed primarily with respect to a soft metal laminate packaging, the cell container is not limited to soft metal packaging and may include a rigid case which maintains good electrical connection between a battery's cell components. In addition, in some cases, a stamped sheet is not used and a "candy wrap" is used to seal the cell container as is well known in the art. It is therefore intended that the scope of the invention should be determined with reference to the appended claims.

What is claimed is:

1. An electrochemical cell comprising:

a cell container having at least one curved surface;

a negative electrode provided within the cell container;

a separator provided within the cell container; and

a positive electrode provided within the cell container, a portion of the positive electrode having a curved surface with substantially the same radius of curvature as the at least one curved surface of the cell container.

2. The electrochemical cell of claim 1 wherein the cell has a ratio between its maximum dimension and minimum dimension between about 3:1 and 300:1.

3. The electrochemical cell of claim 1 wherein the cell container comprises a soft metal laminate packaging.

4. The electrochemical cell of claim 1 wherein the separator comprises a porous film.

5. The electrochemical cell of claim 1 further comprising an electrolyte provided within the cell container.

6. The electrochemical cell of claim 6 wherein the electrolyte comprises an organic solvent including a lithium salt.

7. The electrochemical cell of claim 1 wherein the negative electrode, the separator and the positive electrode are included in one of a jellyroll or a stack.

8. The electrochemical cell of claim 1 wherein the negative electrode comprises a current collector and a lithium ion anode material.

9. The electrochemical cell of claim 1 wherein the cell has a geometry determined by the geometry of an associated electronics device.

10. The electrochemical cell of claim 10 wherein the curved surface has a radius of curvature between about one inch and ten feet.

11. The electrochemical cell of claim 1 wherein the cell has a substantially constant thickness.

12. The electrochemical cell of claim 1 wherein the cell comprises a curved seam.

13. A custom geometry electrochemical cell comprising a cell container having at least one curved surface, a negative electrode provided within the cell container, a separator provided within the cell container, a positive electrode provided within the cell container, a portion of the positive electrode having a curved surface, wherein the custom geometry electrochemical cell has a ratio between its maximum dimension and minimum dimension between about 3:1 and 300:1.

14. The electrochemical cell of claim 13 wherein the cell has a thickness from about 1 millimeter to 20 millimeters and a width from about 10 millimeters to 300 millimeters.

15. The electrochemical cell of claim 13 wherein the negative electrode comprises at least one curved surface which is substantially parallel to the portion of the curved surface of the positive electrode.

16. The electrochemical cell of claim 13 wherein the cell container is not cylindrical.

17. The electrochemical cell of claim 13 wherein the curved surface has a geometry conforming to the geometry of an associated electronics device.

18. The electrochemical cell of claim 13 wherein the cell has a substantially constant thickness along one of its dimensions.

19. The electrochemical cell of claim 13 wherein the negative electrode comprises a current collector and a lithium ion anode material.

20. An electrochemical structure comprising:

a negative electrode having at least one curved surface;

a separator in contact with the negative electrode and in contact with the positive electrode; and

a positive electrode having at least one curved surface, a portion of the positive electrode having a curved surface with substantially the same radius of curvature as the at least one curved surface of the negative electrode.

21. A method of fabricating a custom geometry electrochemical cell, the method comprising:

receiving a positive electrode, a separator and a negative electrode as one or more layers;

inserting the one or more layers into a cell container;

sealing a portion of the cell container; and

laminating the one or more layers, wherein the one or more layers comprise a curved geometry after lamination.

22. The method of claim 21 wherein the custom geometry electrochemical cell has a ratio between its maximum dimension and its minimum dimension between about 3:1 and 300:1.

23. The method of claim 21 wherein the one or more layers are laminated after insertion into the cell container.

24. The method of claim 23 wherein the cell container comprises a curved geometry after lamination.

25. The method of claim 24 wherein a portion of the positive electrode has a curved surface with substantially the same radius of curvature as the curved geometry of the cell container.

26. The method of claim 21 wherein laminating comprises an energy input lamination.

27. The method of claim 26 wherein the energy input lamination uses a custom geometry laminating die.

28. The method of claim 26 wherein the energy input lamination comprises applying pressure to the cell.

29. The method of claim 21 wherein laminating comprises a cooling lamination.

30. The method of claim 29 wherein the cooling lamination comprises applying pressure to the cell.

31. The method of claim 30 wherein cooling lamination comprises the use of a custom die comprising at least one cell reception surface.

32. The method of claim 31 wherein the curved geometry of the one or more layers is provided by the at least one cell reception surface.

33. The method of claim 31 further including injecting an electrolyte into the cell container.

34. The method of claim 31 further including a sealing a second portion of the cell container.

35. The method of claim 34 wherein sealing the second portion occurs after injection of an electrolyte.

36. The method of claim 34 wherein the second portion comprises a curved edge.

37. A method of laminating an electrochemical cell structure comprising one or more layers, each of the layers comprising a negative electrode, a separator and a positive electrode, the method comprising laminating the one or more layers, wherein the one or more layers comprise a curved geometry after the lamination.

38. The method of claim 37 wherein laminating is one of an energy input lamination and a cooling lamination.

39. The method of claim 37 further including a second lamination, wherein the one or more layers comprise the curved geometry after the second lamination.

40. The method of claim 39 wherein the one or more layers comprise the curved geometry after the first lamination.

41. The method of claim 37 wherein the lamination comprises applying an elevated temperature to the cell in the range of about 30 degrees Celsius to 150 degrees Celsius for a duration in the range of about 1/2 minutes to 20 minutes.

42. The method of claim 41 wherein the lamination further comprises applying pressure in the range of about 10 to 300 pounds per square inch to the cell.

43. A custom die for laminating an electrochemical cell structure comprising one or more layers, each of the layers comprising a negative electrode, a separator and a positive electrode, the custom die comprising:

a first plate and having a first cell reception surface corresponding to a desired geometry for a first portion of the custom geometry electrochemical cell structure; and

a second plate and having a second cell reception surface corresponding to a desired geometry for a second portion of the custom geometry electrochemical cell structure, wherein one of the first cell reception surface and the second cell reception surface include a curved surface.

44. The die of claim 43 wherein the first cell reception surface and the second cell reception both include a curved surface which are substantially parallel to each other.

45. The die of claim 43 wherein the one of the first cell reception surface and the second cell reception surface include a radius of curvature between about one inch and ten feet.

46. A method of sealing a portion of an electrochemical cell, the method comprising sealing the portion of the cell using one or more sealing bars, wherein the portion comprises a curved geometry after sealing.

47. The method of claim 46 further including sealing a second portion of the cell container.

48. The method of claim 47 wherein the second portion of the cell comprises a second curved geometry.

49. A custom sealing apparatus for sealing a custom geometry electrochemical cell, the custom sealing apparatus comprising:

a first sealing bar having a first sealing surface corresponding to a desired geometry for a first portion of the custom geometry electrochemical cell; and

a second sealing bar having a second sealing surface corresponding to a desired geometry for a second portion of the custom geometry electrochemical cell, wherein at least one of the first sealing surface and the second sealing surface include curvature.

50. The custom sealing apparatus of claim 49 wherein the desired geometry corresponds to the geometry of an associated electronics device.

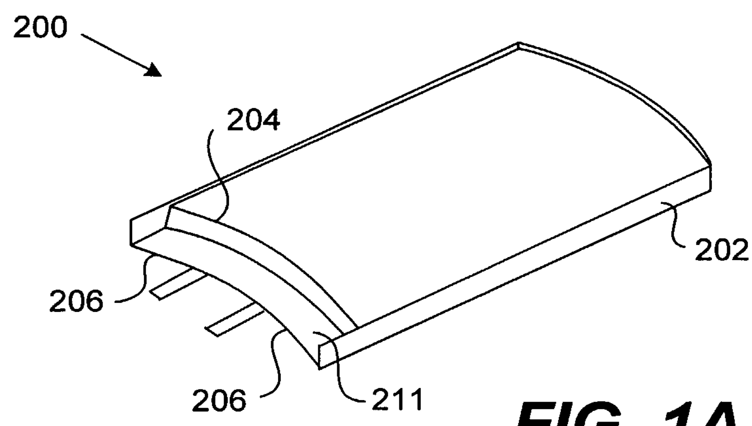

FIG. 1A

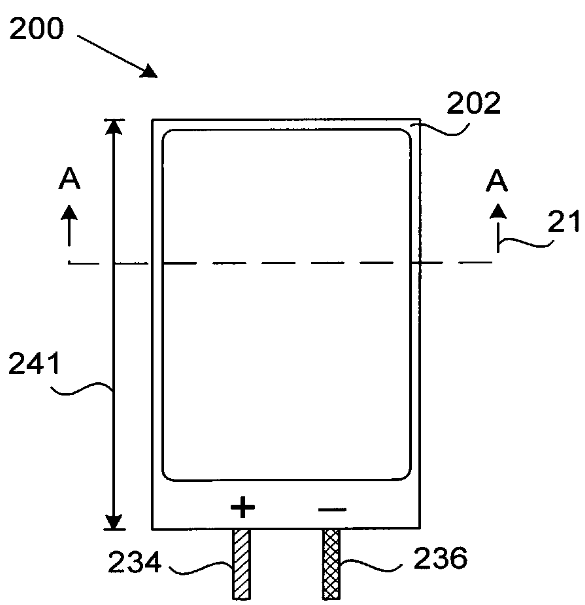

FIG. 1B

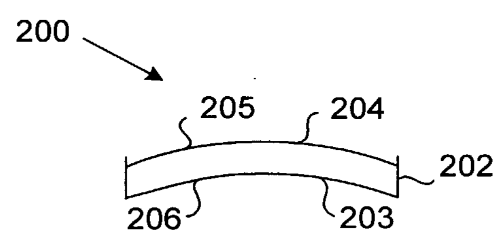

FIG. 1C

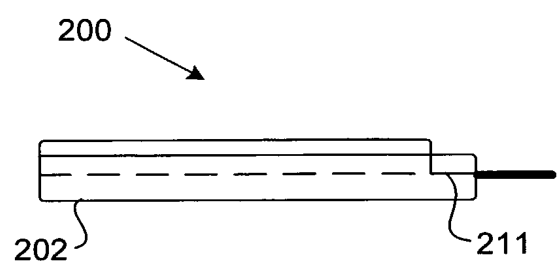

FIG. 1D

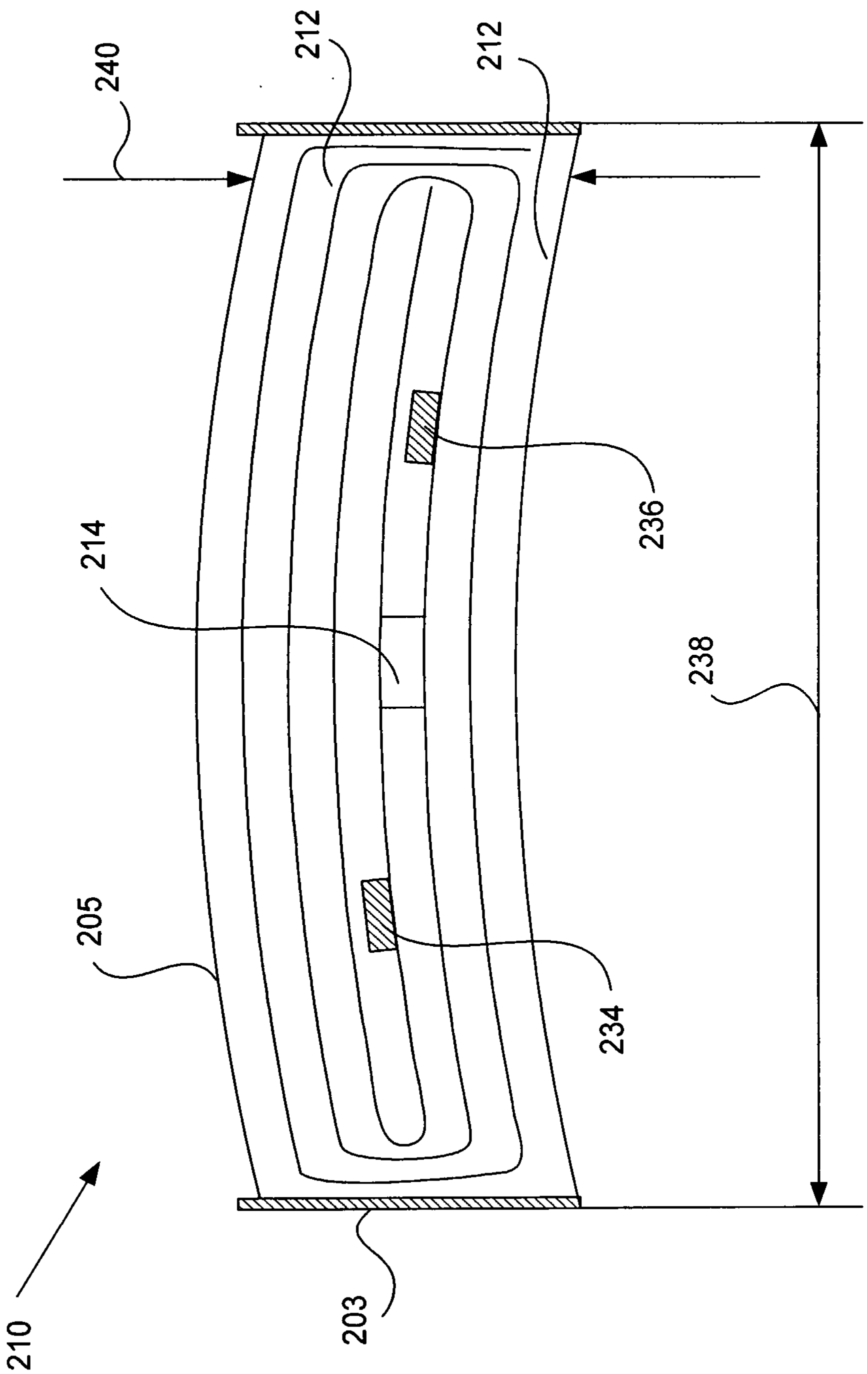

FIG. 2A

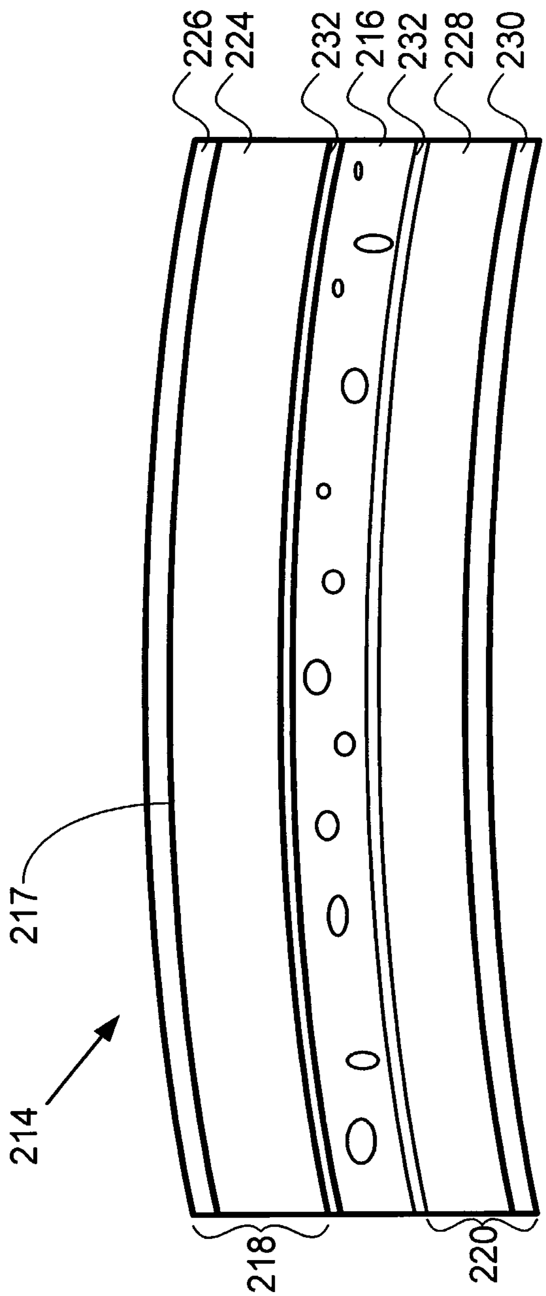

FIG. 2B

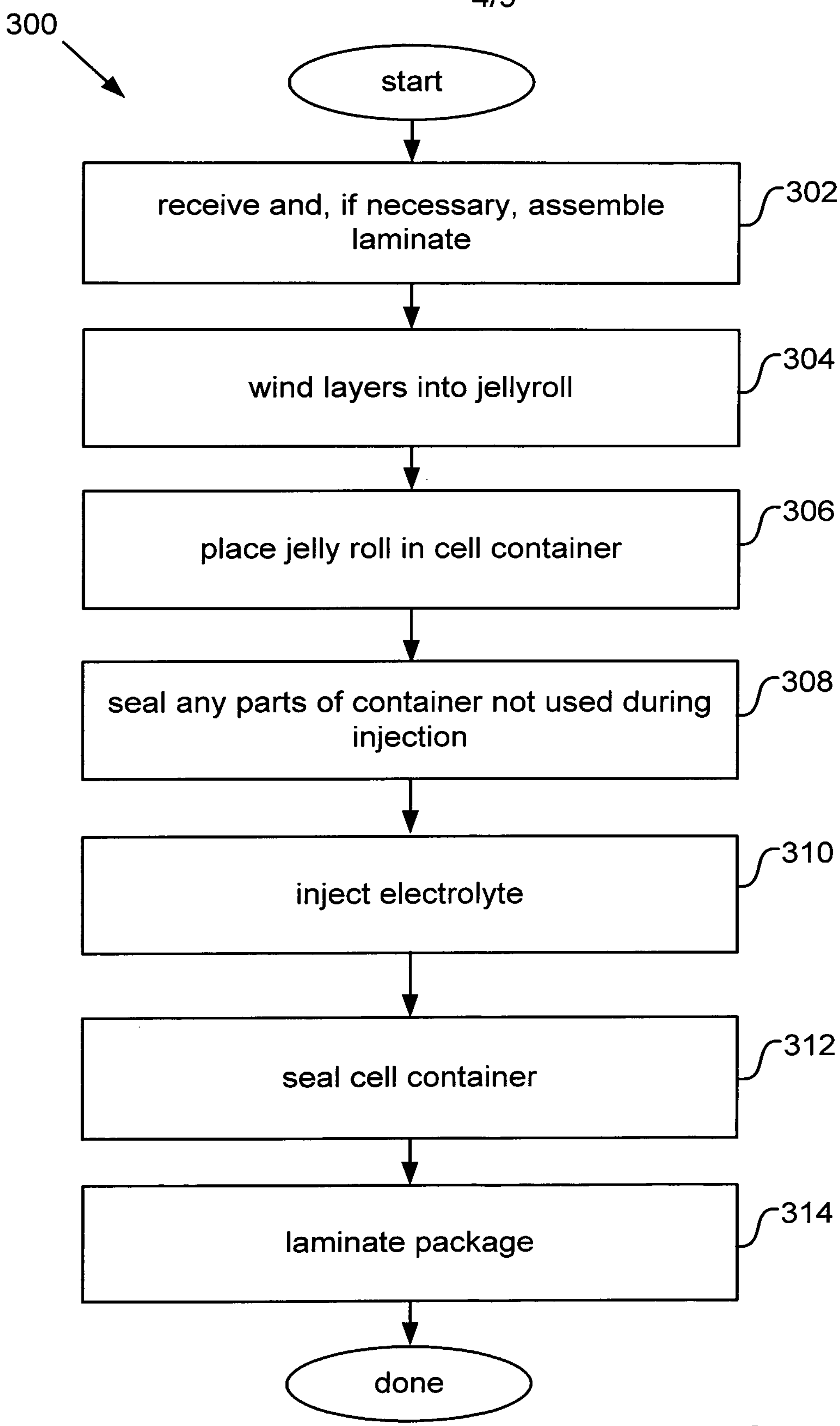
300
start
receive and, if necessary, assemble laminate
302
wind layers into jellyroll
304
place jelly roll in cell container
306
seal any parts of container not used during injection
308
inject electrolyte
310
seal cell container
312
laminate package
314
done

FIG. 3

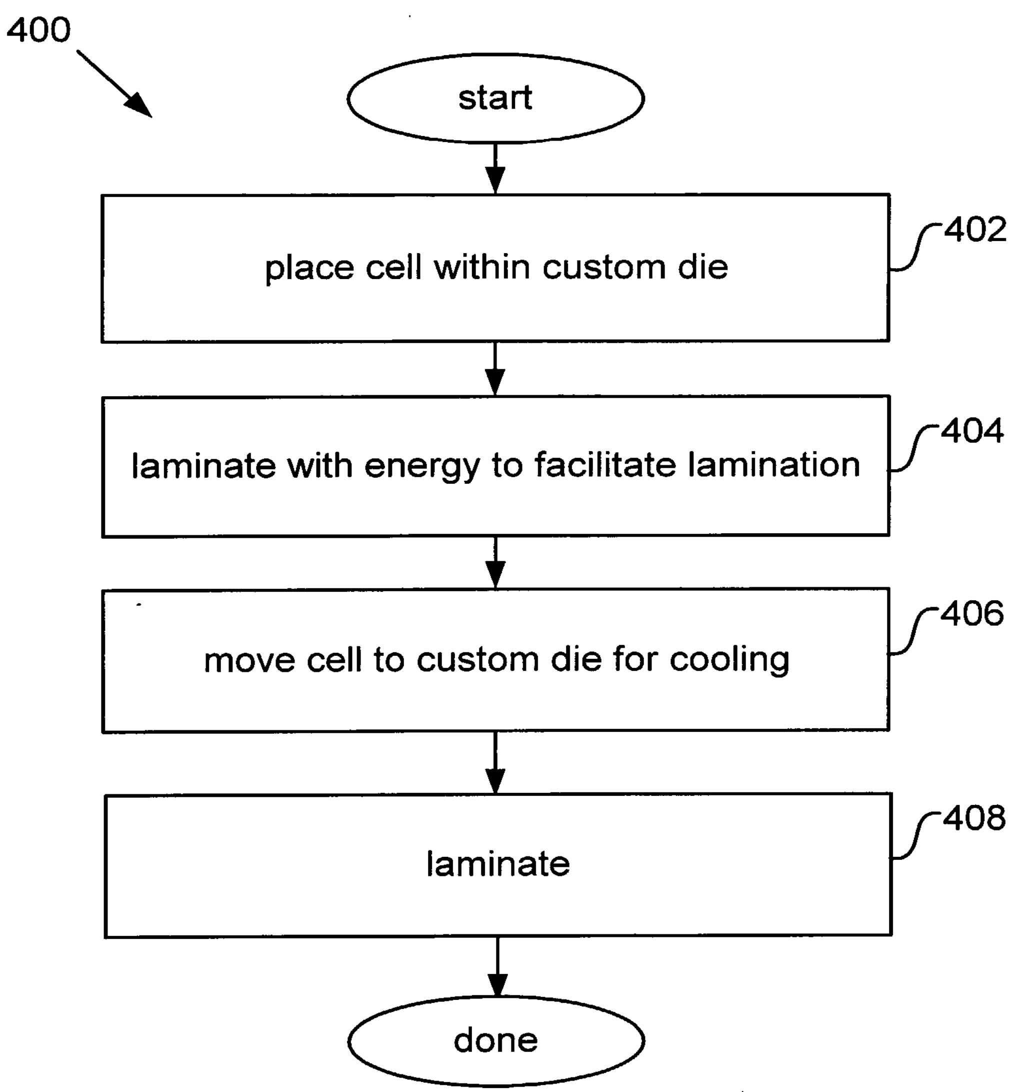
400
start
place cell within custom die
402
laminate with energy to facilitate lamination
404
move cell to custom die for cooling
406
laminate
408
done

FIG. 4A

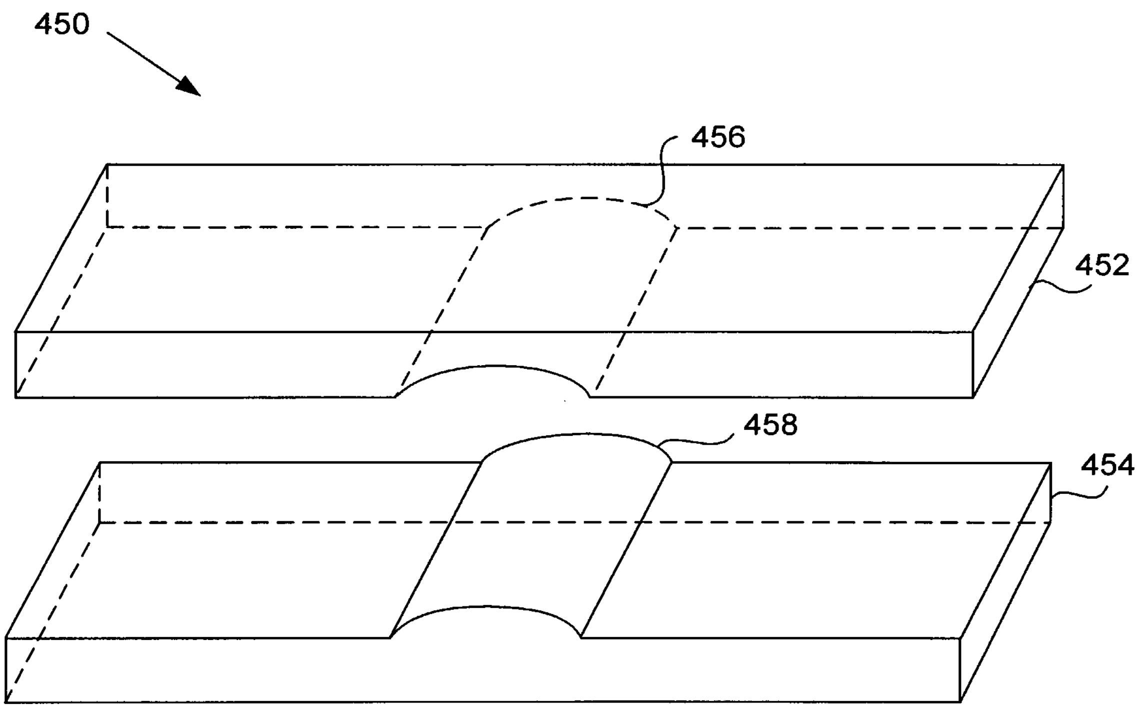

FIG. 4B

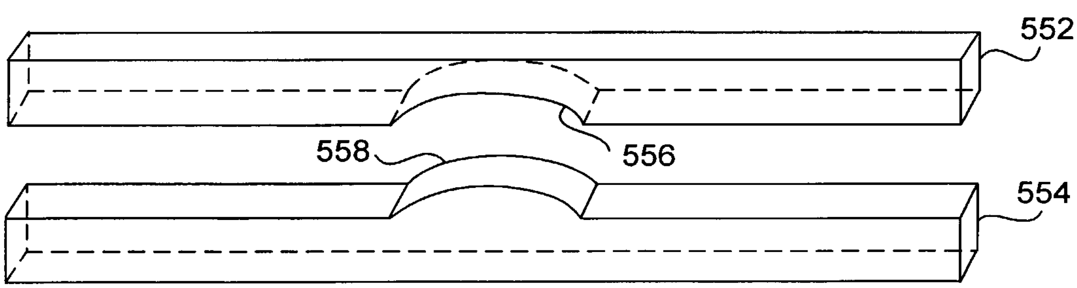

FIG. 5B

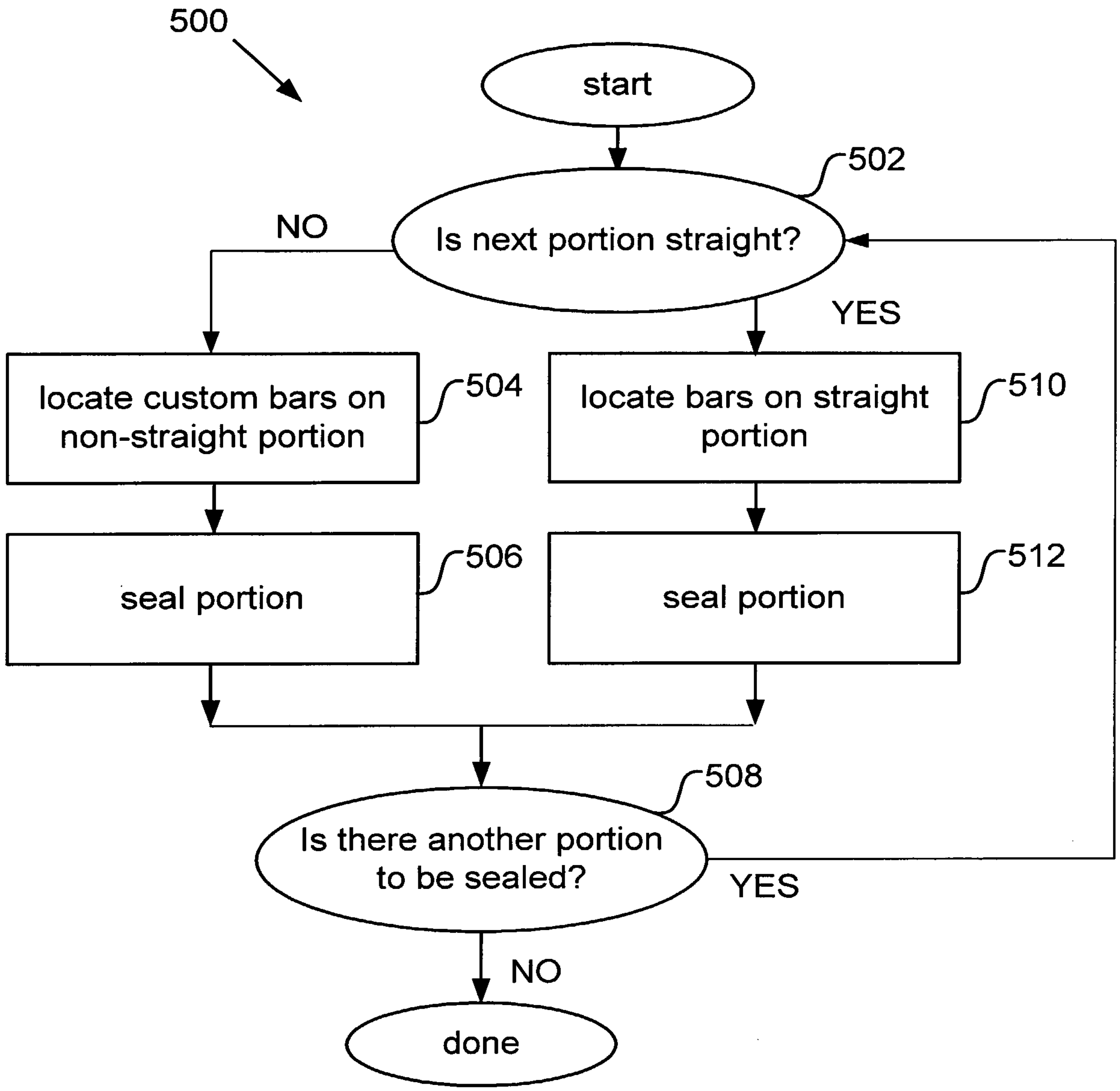
500
start
502
Is next portion straight?
NO
YES
locate custom bars on non-straight portion
504
locate bars on straight portion
510
seal portion
506
seal portion
512
508
Is there another portion to be sealed?
YES
NO
done

FIG. 5A

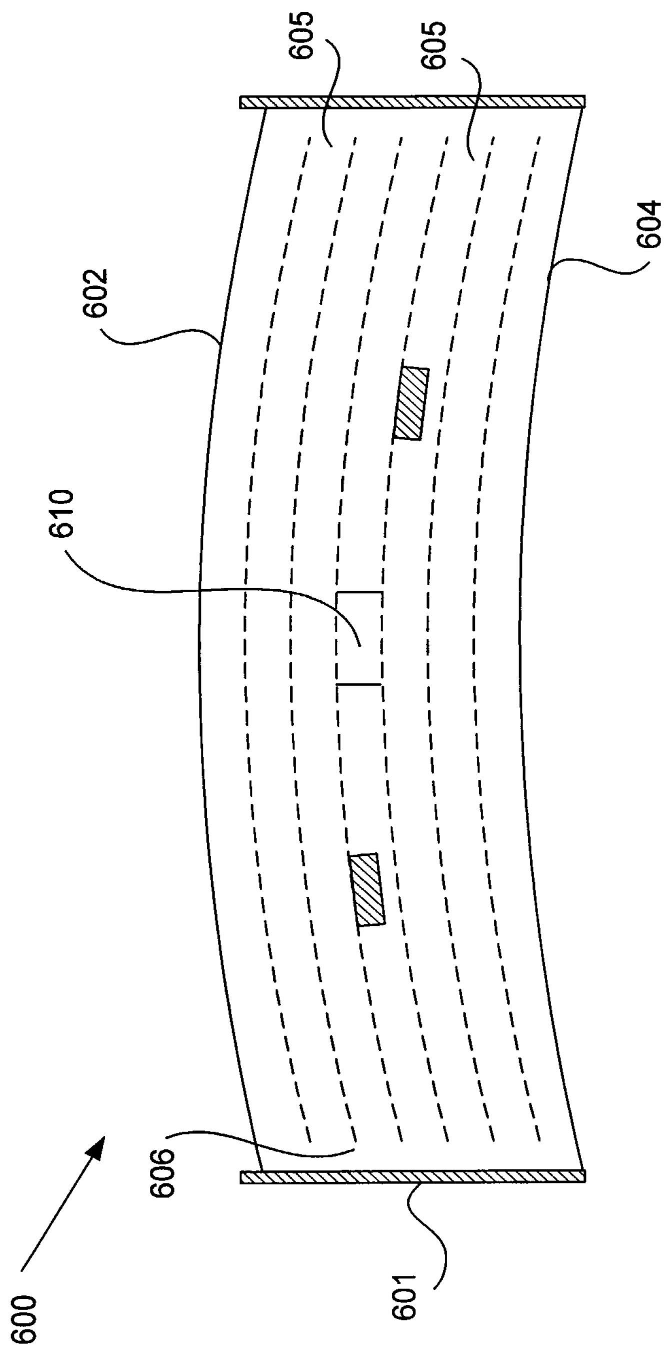

FIG. 6A

FIG. 6B